Seafloor Shear Measurement Using Interface Waves

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LONG-TERM GOALS

The long term goal of our research is to improve the estimation of bottom properties by understanding and incorporating the effects produced by shear.

OBJECTIVES

The objectives of this proposal are to:

- Develop an acoustic/seismic receive system for the estimation of sediment compressional wave speed, compressional wave attenuation and shear wave speed.
- Develop new inversion techniques for shear properties: A new inversion scheme is being developed to estimate shear properties of the sediment using interface wave dispersion.

APPROACH

Figure 1 shows the conceptual schematic of the system.This shear measurement system consists of the following components:

1. Sled: The sled houses the data acquisition system. The sled will be connected to a tow cable with appropriate chain and floatation to isolate the wave motion from the geophone/ hydrophone receive array. The termination of the tow cable at the surface will consist of a float and appropriate mechanical connectors to deploy, move, leave, and recover the system.
2. Acquisition System: Two Several Hydrophone Receive Systems (SHRUs) serve as the data collection system.
3. Receive array: The receive array consists of gimbaled geophones and hydrophones. There will be a float connected to the geophone end of the system as a backup in case the other float is lost. The geophone end will be properly weighed down to filter out the surface wave motions by a chain and/or weight.

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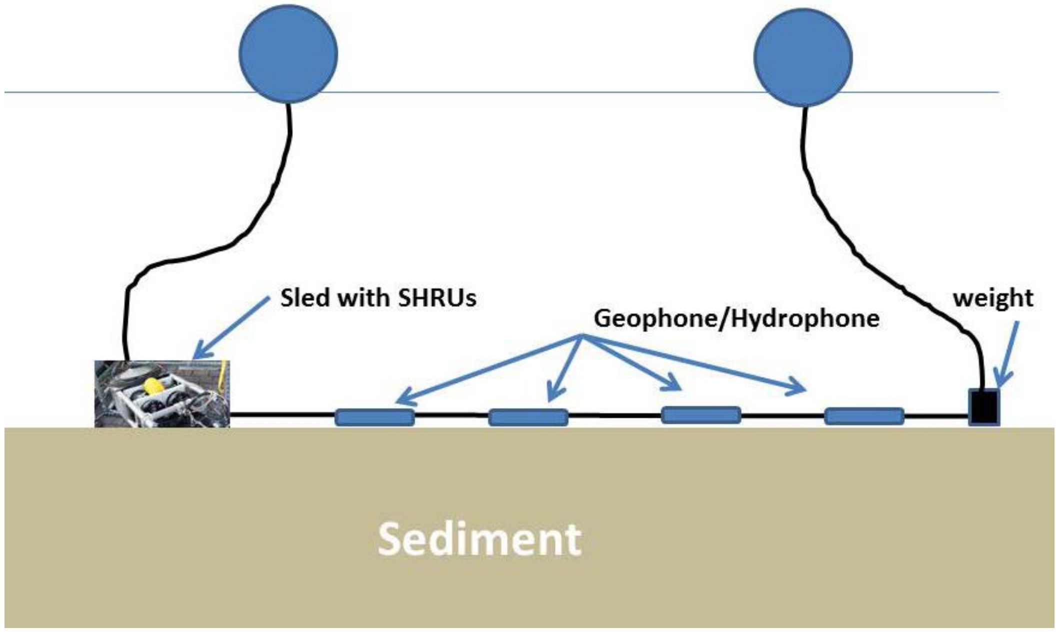

Figure 1. Shear measurement system consisting of a geophone/hydrophone array and data collection system (SHRU)

WORK COMPLETED

All the components of the shear measurement system have been acquired. The SHRUs were built at WHOI and have been delivered to URI. Figure 2 shows the pictures of the SHRU data acquisition systems and the geophone array. The system was tested on land and in shallow water. One of our graduate students, Jeannette Greene, was involved in the design and testing of this system including the sled which houses the data collection system.

Figure 2. Left panel shows the two SHRU data collection systems. Right panel shows the geophone array consisting of gimbaled geophones.

RESULTS

A limited seabed test, using some of the components of the shear measurement system, was conducted north of the R/V Endeavor Pier in the Narragansett Bay Campus of the University of Rhode Island on March, 2011. One SHRU and a four geophone array were deployed off the stern of R/V Endeavor in approximately 6 m of water. The geophones were properly placed, with a spacing of 5 m underwater, with the help of divers. A 300 lbs weight was released from just below the surface of the water off the stern of R/V Endeavor using the ship's capstan. Data were collected by repeating the weight drops ten times.

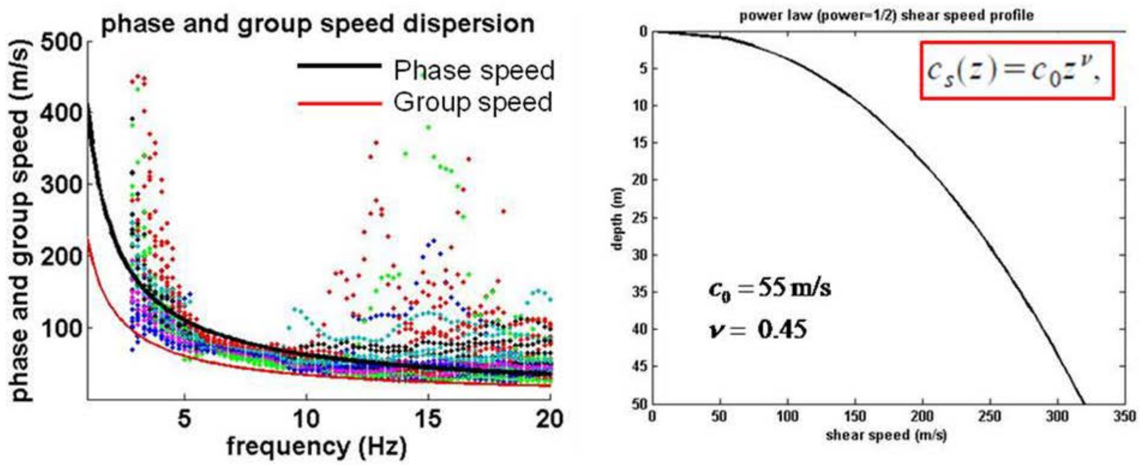

Figure 3 shows the phase velocity estimates (in color dots) from all possible geophone-event pairs (left panel). The continuous lines are theoretical group and phase velocity curves calculated using the Chapman-Godin approach for mode 1.The right panel shows shear wave speed profile used to calculate the theoretical group and phase speed curves shown in the left panel.

The signals received on the four geophones were used to calculate the phase velocity as a function of frequency. Cross spectral density between signals from a geophone pair provides an estimate of the phase difference between them. Phase velocity is calculated knowing the phase difference. The phase speeds calculated using all the possible event-geophone pairs are shown in Figure 3 (left panel). The phase velocity estimates from different event-geophone pairs are shown in different colors in this figure. As can be seen from the figure, the phase velocity estimates tend to become noisy at frequencies close to above 20 Hz. The phase and group speeds calculated theoretically based on Chapman- Godin approach[1] is overlaid on the data in the figure. The theoretical curves shown in the figure correspond to mode 1. A time-frequency analysis of the time series data also confirmed the presence of mode 1 at this frequency band. It should be noted that the phase speed estimation assumes range independent sediment properties which is a reasonable assumption given that the ranges involved are very small in the present test. The theoretical phase and group velocity curves shown in the left panel of Figure 3 have been calculated based on a shear wave speed profile shown in the right panel. The shear wave speed profile ($c_s(z)$) shown in the right panel is a power law approximation

($c_s(z) = c_0 z^{\nu}$) with c_0= 55 m/s and ν=0.45. The values of c_0 and ν were arrived at iteratively by choosing trial values for c_0 and ν, so that the phase speed dispersion matches the Scholte wave dispersion data as shown in the left panel.

Another full-scale sea test was conducted during 22-25 August 2011 in Narragansett Bay and off Block Island, RI. One of the locations of testing, north-east of Block Island in 40 ft of water depth, is shown in panel B of Figure 4. We accomplished three days of testing of the geophone array and the Combustive Sound Source (Preston Wilson, ARL, UT Texas) which were deployed by R/V Shanna Rose. Two SHRUs were housed in a sled and the geophone/hydrophone array was laid out behind the sled (as shown in Figure 1). Panel A in Figure 4 shows the sled with the SHRUs is ready for deployment. The geophone array was deployed after the sled and the sled was dragged for a short distance to straighten out the array. The data is being process now and initial look at the data indicates that the test was a successful one. The time-series recorded in one of the four geophones due to a CSS shot is shown in panel C of Figure 3. Y-axis indicates the amplitudes of the vertical velocity and x-axis is arbitrary time.

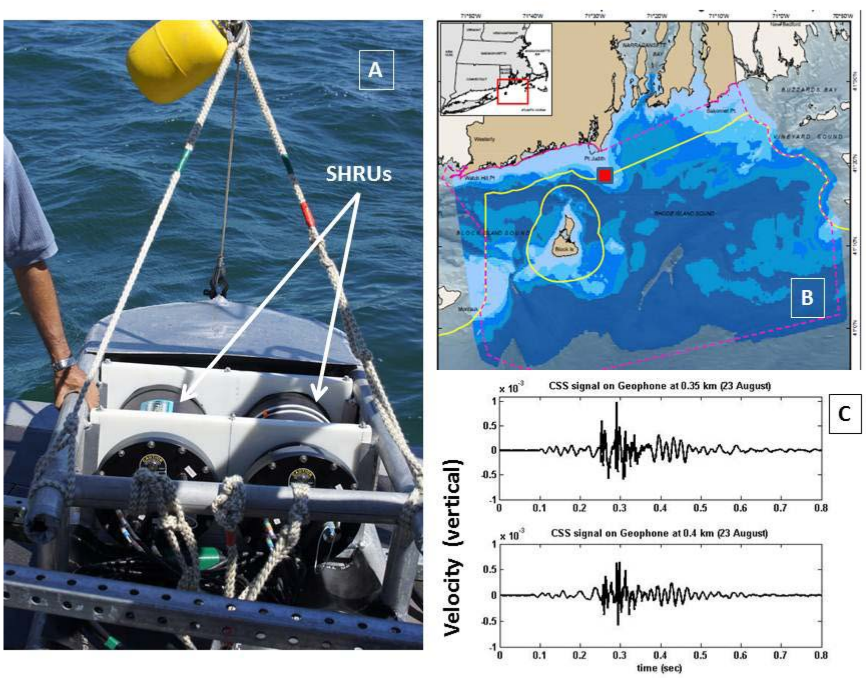

Figure 4. The sled which houses the SHRUs is ready to be deployed (panel A). The geophone array will follow the sled into the water. One of the locations were the geophone array was deployed during the August, 2011 sea test (panel B). Panel C shows the first look at the data on a geophone from two shots at 0.35 km (upper panel) and 0.4 km (lower panel). Y-axis indicates the amplitudes of the vertical velocity and x-axis is arbitrary time.

We plan to complete the processing of the data from the test and try to invert for the shear properties of the bottom using the method adopted in our earlier test. We have some ground- truth measurements available in some of the test locations in the form of geotechnical information. These were collected as part of the Rhode Island Offshore Wind Farm study. We plan to use this data to compare and validate our shear speed estimate.

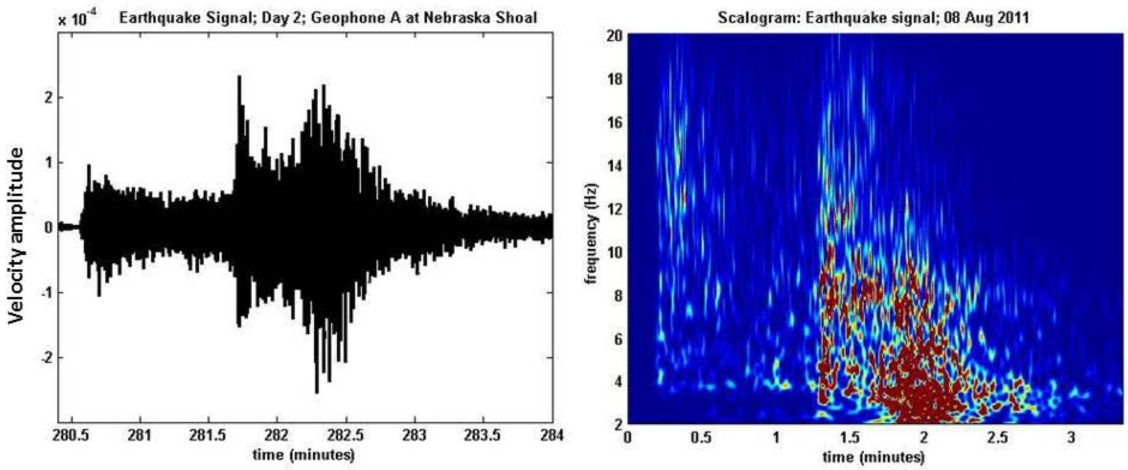

Figure 5: Signals generated by the East Coast earthquake on August 23, 2011 at approximately 17:52:30 UTC, received at one of the geophones. This sensor was at (41.35965582, -71.55043477). The x- axis is in minutes since switching on the data acquisition system (which was at 13:11:52 UTC)

An earthquake event occurred during our sea test and the geophones pick up the signal for that event. Figure 5 shows the ground motion (left panel) and the time-frequency representation (right panel). The origin time of the earthquake in Virginia was at 17:51:04 UTC (13:51:04 EDT) on Tuesday, August 23, 2011. The initial arrival got to Rhode Island at around 17:52:30 UTC (13:52:30 EDT).

IMPACT/APPLICATIONS

The inversion scheme using interface waves is suitable for estimation of acoustic properties of sediments in shallow water. Our receive system can be easily deployed at multiple locations. Using multiple deployment of the receiver, sediment properties can be estimated along various tracks which would allow an area to be mapped. This new system and the estimation of shear speed compliments our long range sediment tomography technique, which estimates compressional wave speed and attenuation.

TRANSITIONS

The sediment parameters obtained by this inversion will compliment the forward modeling efforts. The sediment tomography technique is suitable for forward force deployment when rapid assessment of environmental characteristics is necessary.

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1. Jeanette Greene, Jennifer Giard, Gopu R. Potty and James H. Miller, "A Measurement System for Shear Speed Using Interface Wave Dispersion," Proceedings of the International Symposium on Ocean Electronics (SYMPOL), November 16-18, Kochi, India, 2009 (accepted).
2. Gopu R. Potty, Huikwan Kim and James H. Miller, "Acoustic Radiation from Offshore Wind Farms," Proceedings of the International Symposium on Ocean Electronics (SYMPOL), November 16-18, Kochi, India, 2009 (accepted).
3. Gopu R. Potty and James H. Miller, "Long Range Sediment Tomography in the East China Sea," in *Shallow Water Acoustics,* J. Simmen, E. S. Livingston, J-X Zhou and F-H Li eds., AIP Conference Proceedings, 255-261, 2010.

OTHER PUBLICATIONS

1. Georges Dossot, *Acoustic Fluctuations in Shallow Water due to Nonlinear Internal Waves*, Doctoral Dissertation, University of Rhode Island, 2011.
2. Jeannette Greene, *Development of an Amphibious Seismo-Acoustic Recording System*, Master's Thesis, University of Rhode Island, 2011
3. James H. Miller, Gopu R. Potty, Kathleen Vigness Raposa, David S. Casagrande, Lisa A. Miller, Jeffrey A. Nystuen, Peter M. Scheifele, and John Greer Clark, "Assessment of the acoustic effects of offshore wind turbines on the marine ecosystem," J. Acoust. Soc. Am. Volume 128, Issue 4, pp. 2331-2331 (October 2010).
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HONORS/AWARDS/PRIZES

James Miller and Gopu Potty participated in the Second INDO – US Workshop on Shallow Water Acoustics, National Institute of Ocean Technology (NIOT), Chennai, India, February 9-11, 2011.

Gopu Potty offered a week long course on *Ocean Acoustics* for emerging researchers and scientists in India at National Institute of Ocean Technology (NIOT), Chennai, India, February 2-8, 2011. This course was sponsored by ONR and NIOT, India.

Gopu Potty was appointed as Associated Editor for IEEE Journal of Oceanic Engineering starting July, 2011.

James Miller and Gopu Potty were approved as co-chairs of the Acoustical Society of America Providence, RI meeting to be held in 2014.

Gopu Potty was nominated to the Advisory Committee and Technical Program Committee of the International Symposium on Ocean Electronics organized by the Cochin University of Science and Technology in Cochin, India (November, 2011).

James Miller has been nominated for President of the Acoustical Society of America and the election is schedule for 2012.